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(54) **Microwave processing of MIM preforms**

(57) A method of producing a metallic component includes: providing a mixture of a metallic powder and a binder; melting the mixture and forming the mixture into a preform (48) in the shape of the component; remove a majority of the binder from the preform (48); and heating the preform (48) with microwave energy to remove the remainder of the binder and to sinter the metal powder together to form the component. The component may be formed as an individual component or continuously.

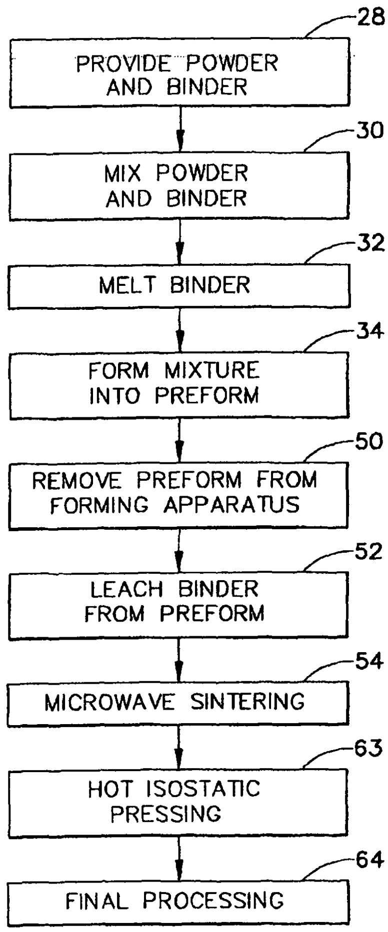

FIG. 2

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Description

[0001] This invention relates generally to sintered metallic components and more particularly to components sintered by microwave heating.

[0002] Metal Injection Molding ("MIM") is a known process in which a fine metallic powder is mixed with a plastic binder and extruded to a desired shape using plastic molding equipment. The resulting preform is washed to remove a large portion of the plastic from the powder. Subsequent sintering consolidates the preform to form a finished component.

[0003] Prior art methods of sintering for MIM preforms require furnace heat treatment at temperatures capable of causing the metal powders to sinter together to make the preform mechanically strong enough for further processing. This is a time consuming process that results in a non uniform product due to the heating process being "from the outside in", meaning the outer portion of the preform gets more time at high temperature and can sinter earlier causing voids to be trapped inside the preforms. This can also result in non-uniform mechanical properties.

[0004] Accordingly, there is a need for a method of sintering a metallic preform to provide a uniformly dense finished component.

[0005] The above-mentioned need is addressed by the present invention, which according to one aspect provides a method of producing a metallic component including: providing a mixture of a metallic powder and a binder; melting the binder and forming the mixture into a preform in the shape of the component; remove a majority of the binder from the preform; and heating the preform with microwave energy to remove the remainder of the binder and to sinter the metal powder together to form the component.

[0006] According to another aspect of the invention, a method of producing a metallic component includes providing a mixture of a metallic powder and a binder; melting the binder and forming the mixture into a continuous preform in the shape of a desired component; removing a majority of the binder from the preform; and heating the preform with microwave energy to remove the remainder of the binder and to sinter the metallic powder together to form the component.

[0007] The invention may be best understood by reference to the following description taken in conjunction with the accompanying drawing figures in which:

Figure 1 is a perspective view of a compressor blade constructed in accordance with an embodiment of the present invention;

Figure 2 is block diagram of a manufacturing process carried out in accordance with an embodiment of the present invention;

Figure 3 is a schematic side view of an injection molding apparatus;

Figure 4 is a schematic side view of a preform being removed from the mold show in Figure 3;

Figure 5 is a schematic cross-sectional view of a preform inside a microwave chamber;

Figure 6 is schematic side view of an apparatus for carrying out an alternative molding and sintering process;

Figure 7 is a schematic perspective view of a weld wire produced in an embodiment of the present invention;

Figure 8 is a schematic perspective view of the weld wire of Figure 7 wound onto a spindle for further processing;

Figure 9 is a schematic view of an alternative extruding apparatus; and

Figure 10 is a schematic perspective view of a metallic sheet wound onto a spindle for further processing.

[0008] Referring to the drawings wherein identical reference numerals denote the same elements throughout the various views, Figure 1 depicts an exemplary compressor blade 10 for a gas turbine engine. The present invention is equally applicable to the construction of other types of metallic components, non-limiting examples of which include rotating turbine blades, stationary turbine vanes, turbine shrouds, and the like. The compressor blade 10 comprises an airfoil 12 having a leading edge 14, a trailing edge 16, a tip 18, a root 19, and opposed sides 20 and 22. An arcuate inner platform 24 is attached to the root 19 of the airfoil 12. A dovetail 26 extends downward for mounting the blade 10 in a rotor slot. The compressor blade 10 is made from a metal alloy suitable for the intended operating conditions.

[0009] Figure 2 depicts the process for constructing the compressor blade 10 according to the method of an embodiment of the present invention. Initially, as shown in block 28, a metallic powder and a suitable binder are provided.

[0010] The metallic powder may be a single alloy or it may be a mechanical mixture of more than one alloy. For optimum performance in the injection molding process and also for compatibility with the microwave heating step described below, the particle size of the metallic powder should be about 100 micrometers or less. Examples of known alloys suitable for constructing compressor blades include titanium alloys such as Ti-6Al-4V, nickel-based alloys such as INCO 718 or UDIMENT 720, and iron-based alloys such as A286.

[0011] The binder may be any material which is chemically compatible with the metallic powder and which allows the required processing (e.g. mixing, injection, solidification, and leaching). Examples of known suitable binders include waxes and polymer resins. The binder may be provided in a powder form.

[0012] The binder and the metallic powder are thoroughly mixed together, as shown in block 30. The mixture is then heated to melt the binder and create a fluid with the metallic powder coated by the binder (block 32). Next, the mixture is formed into a predetermined shape at block 34. One way of forming the mixture is to use a known injection-molding apparatus. A schematic view of an injection molding apparatus 36 including a hopper 38 and an extruder 40 with rotating screw 42 is shown in Figure 3. The mixture is extruded into the cavity 44 of a mold 46. The mold 46 may optionally be heated to avoid excessively rapid solidification of the binder which would result in a brittle preform 48. Instead of melting the binder in a discrete batch, the mixture could be molded in a continuous manner using known injection molding equipment capable of melting the binder as it passes through the screw 42. Once the mixture has solidified, the mold 46 is opened as shown in Figure 4 and the resulting uncompacted or "green" preform 48 is removed (see block 50 in Figure 2).

[0013] The preform 48 comprises metal particles suspended in the solidified binder. The preform 48 is not suitable for use as a finished component, but merely has sufficient mechanical strength to undergo further processing. At block 52 of Figure 2, the preform 48 is leached to remove the majority of the binder. This may be done by submerging or washing the preform 48 with a suitable solvent which dissolves the binder but does not attack the metallic powder.

[0014] Next, at block 54, the preform 48 is microwave sintered. As shown in Figure 5, The preform 48 is placed in a chamber 56 which includes means for creating a suitable atmosphere to prevent undesired oxidation of the preform 48 or other reactions during the sintering process. In the illustrated example a supply 58 of inert gas such as argon is connected to the interior of the chamber 56. The sintering could also be performed under a vacuum. A microwave source 60 such as a known type of cavity magnetron with an output in the microwave frequency range is mounted in communication with the chamber 56. The microwave spectrum covers a range of about 1 GHz to 300 GHz. Within this spectrum, an output frequency of about 2.4 GHz is known to couple with and heat metallic particles without passing through solid metals.

[0015] The microwave source 60 is activated to irradiate the preform 48. In the illustrated example the microwave source 60 is depicted as having a direct line-of-sight to the entire preform 48. However, it is also possible to configure the chamber 56, which would typically be metallic, so that the preform is heated by a combination of direct and reflected microwaves. Because of the small metallic particle size in the preform 48, the microwaves 62 couple with the particles and heat them. The preform 48 is heated to a temperature below the liquidus temperature of the metallic powder and high enough to cause the metallic powder particles to fuse together and consolidate. The high temperature also melts and drives out any remaining binder. The preform 48 is held at the desired temperature for a selected time period long enough to result in a consolidated compressor blade 10. The heating rate (i.e. the output wattage of the microwave source) is selected depending on variables such as the mass of the preform 48, the shape of the chamber 48 and the and the desired cycle time of the sintering process. When compared to prior art methods, the combination of the MIM-formed preform 48 with the microwave sintering step gives the compressor blade 10 a significantly greater density, that is, freedom from voids, in less time.

[0016] When the sintering cycle is complete, the compressor blade 10 is removed from the chamber 56 and allowed to cool. When required, the compressor blade 10 may be subjected to further consolidation using a known hot isostatic pressing ("HIP") process to result in a substantially 100% dense component, as noted in block 63 of Figure 2. If desired, the compressor blade 10 may be subjected to additional processes such as final machining, coating, inspection, etc. in a known manner (see block 64 of Figure 2).

[0017] Figures 6 and 7 illustrate an alterative method suitable for producing continuous components. Initially, a metallic powder and a suitable binder are provided. The metallic powder may be a single alloy or it may be a mechanical mixture of more than one alloy. For optimum performance in the injection molding process and also for compatibility with the microwave heating step described below, the particle size of the metallic powder should be about 100 micrometers or less in diameter. This process is particularly suitable for alloys which are difficult to cold work and which are ordinarily cast. Examples of such alloys include so-called "superalloys" based on nickel or cobalt and containing a high percentage of a gamma-prime phase component. Examples of such alloys include RENE 77, RENE 80, and RENE N4 and N5 nickel-based alloys.

[0018] The binder may be any material which is chemically compatible with the metallic powder and which allows the required processing (e,g: mixing, injection, solidification, and leaching). Examples of known suitable binders include waxes and polymer resins. The binder may be provided in a powder form.

[0019] The binder and the metallic powder are thoroughly mixed together. The mixture is then heated to melt the binder and create a fluid with the metallic powder coated by the binder. Next, the mixture is extruded using known injection-molding apparatus. A schematic view of an injection molding apparatus 136 including a hopper 138 and an extruder 140 with rotating screw 142 is shown in Figure 6. The mixture is extruded through a die 144 of a known type to produce a continuous preform 148 of a constant cross-section. For example, a die 144 having a circular opening of about 1.27 mm (0.050 in.) in diameter may be used to produce a preform 148 for use as a welding filler wire. The die 144 may optionally be heated to avoid excessively rapid solidification of the binder which would result in a brittle preform 148. Once the preform 148 has solidified, it passes along a conveyer belt 150 or other suitable transport mechanism.

[0020] The conveyor belt 150 carries the preform 148 through a solvent bath 152 which leaches the majority of the binder out of the preform 148. This may be done with a suitable solvent which dissolves the binder but does not attack the metallic powder.

[0021] The preform 148 then passes into a sintering chamber 156 where it is microwave sintered. As shown in Figure 6, The chamber 156 includes means for creating a suitable atmosphere to prevent undesired oxidation of the preform 148 or other reactions during the sintering process. In the illustrated example a supply 158 of inert gas such as argon, or a gas fore creating a reducing atmosphere such as hydrogen is connected to the interior of the chamber 156. The processing could also be performed under a vacuum. A microwave source 160 similar to the source 60 described above is mounted in communication with the chamber 156. The microwave source 160 is activated to irradiate the preform 148. Because of the small metallic particle size in the preform 148, the microwaves couple with the particles and heat them. As the preform 148 passes through the chamber 156, it is heated to a temperature below the liquidus temperature of the metallic powder and high enough to cause the metallic powder to fuse together and consolidate. The high temperature also melts and drives out any remaining binder. The heating rate (i.e. the output wattage of the microwave source) and the speed of the conveyor belt 150 are selected so that the preform 148 is held at the desired temperature for a selected time period long enough to result in a consolidated completed component 162. Figure 7 illustrates a short section of the component 162, which in this case is a welding filler wire 162. When compared to prior art methods, the combination of the MIM-formed preform 148 with the microwave sintering step gives the filler wire 162 a significantly greater density, that is, freedom from voids, in less time.

[0022] When the sintering cycle is complete, the component 162 passes out of the chamber 156 and allowed to cool. If desired, the product 162 may be subjected to additional processes such as coating, inspection, etc. in a known manner.

[0023] When required, the welding filler wire 162 may be subjected to further consolidation using a known hot isostatic pressing ("HIP") process to result in a substantially 100% dense component. As shown in Figure 8, This step may be facilitated by winding the welding filler wire 162 on to a spindle 164, with a small spacing "S" between the individual coils. The loaded spindle 164 may then be placed into a chamber (not shown) for the HIP process.

[0024] The continuous process described above may be used to produce any other type of component with a constant cross-section. For example, the process may be used to produce sheet materials. As shown schematically in Figure 9, this may be done by providing a die 244 of the desired width "W" for extruding a wide, thin preform 248. In order to supply an adequate feed of a binder-metallic power mixture to the die 244, a plurality of side-by side injection molding apparatuses 236 may be provided. The extruded preform 248 is then leached and microwave sintered as described above, to result in a metallic sheet 262, shown in Figure 10.

[0025] When required, the metallic sheet 262 may be subjected to further consolidation using a HIP process to result in a substantially 100% dense component. As shown in Figure 10, This step may be facilitated by winding the metallic sheet on to a spindle 264. A release compound may be placed between the layers of the metallic sheet 262 to prevent undesired consolidation and diffusion bonding of the layers. The loaded spindle 264 may then be placed into a chamber (not shown) for the HIP process.

[0026] The foregoing has described a manufacturing process for microwave sintered components. While specific embodiments of the present invention have been described, it will be apparent to those skilled in the art that various modifications thereto can be made without departing from the spirit and scope of the invention. Accordingly, the foregoing description of the preferred embodiment of the invention and the preferred mode for practicing the invention are provided for the purpose of illustration only and not for the purpose of limitation, the invention being defined by the claims.

Parts List

10	compressor blade
12	airfoil
14	leading edge
16	trailing edge
18	tip
19	root
20	opposed sides
22	opposed sides
24	arcuate inner platform
26	dovetail
28	block
30	block
32	block
34	block
36	injection molding apparatus
38	hopper

(continued)

40	extruder
42	screw
44	cavity
46	mold
48	preform
50	block
52	block
54	block
56	chamber
58	supply
60	microwave source
62	microwaves
136	injection molding apparatus
138	hopper
140	extruder
142	rotating screw
144	die
148	preform
150	conveyor belt
152	solvent bath
156	chamber
158	supply
160	microwave source
162	component/welding filler wire
164	spindle
236	injection molding apparatuses
244	die
248	preform
262	metallic sheet
264	spindle

Claims

1. A method of producing a metallic component, comprising:

    providing a mixture of a metallic powder and a binder;
    melting said binder and forming said mixture into a preform (48) in the shape of said component;
    removing a majority of said binder from said perform (48); and
    heating said preform (48) with microwave energy to remove the remainder of said binder and to sinter said metal powder together to form said component.

2. The method of claim 1 further comprising performing a hot isostatic pressing treatment on said component after said heating step.

3. The method of claim 1 or claim 2 wherein the step of forming said mixture into a preform (48) comprises injecting said mixture into a mold having a desired shape.

4. The method of any preceding claim wherein the step of forming said mixture into a preform (48) comprises extruding said mixture through a die (144, 244) having a desired cross-sectional shape.

5. The method of any preceding claim wherein said majority of said binder is removed by washing said preform (48) with a solvent selected to dissolve said binder but not said metallic powder.

6. The method of any preceding claim wherein said preform (48) is disposed in a chamber (56) provided with a controlled composition atmosphere during said heating.

7. The method of any preceding claim wherein said preform (48) is maintained under a vacuum during said heating.

8. The method of claim 4 or any dependent thereon wherein said preform (48) is sequentially transported from said die (144, 244) through a solvent bath (152) for leaching said binder and then to a chamber (156) wherein said microwave heating is carried out.

9. The method of claim 4 or any claim dependent thereon wherein said die (144, 244) has an elongated cross-sectional shape adapted to produce a sheet-like preform.

10. The method of claim 4 or any claim dependent thereon further comprising:

    coiling a length of said component onto a spindle (264) with a release compound disposed between adjacent layers of said component;
    placing said spindle (264) in a chamber; and
    performing a hot isostatic pressing treatment on said component.

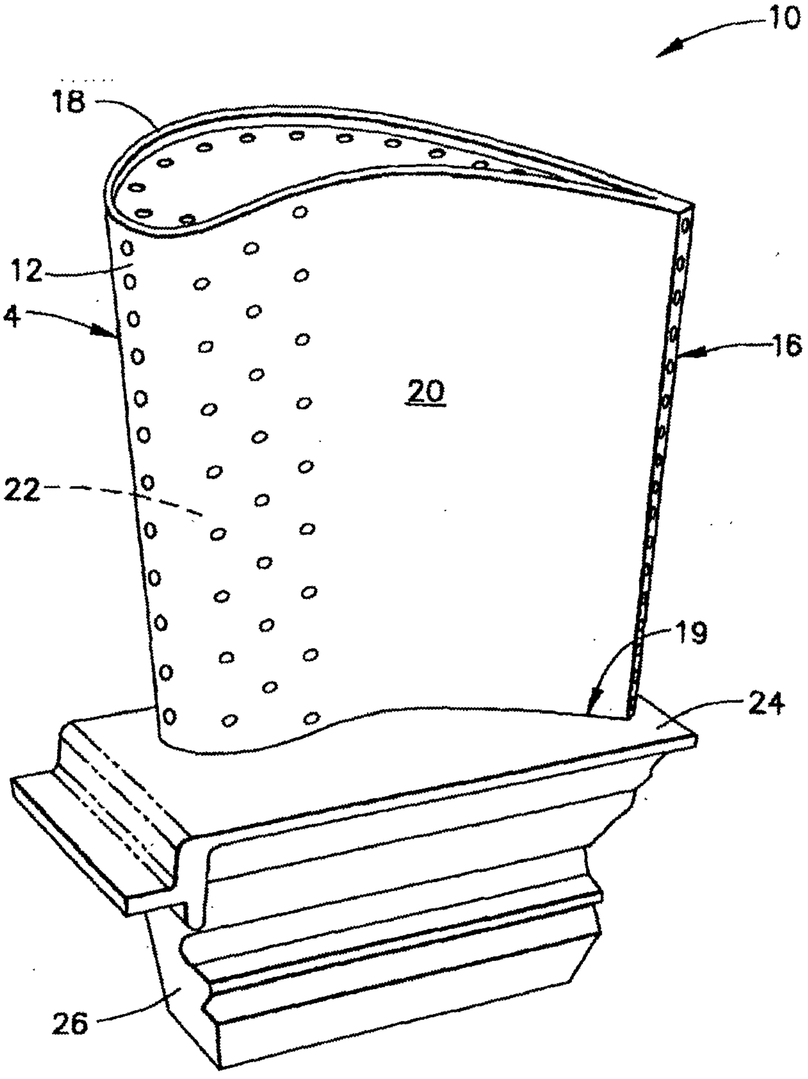

FIG. 1

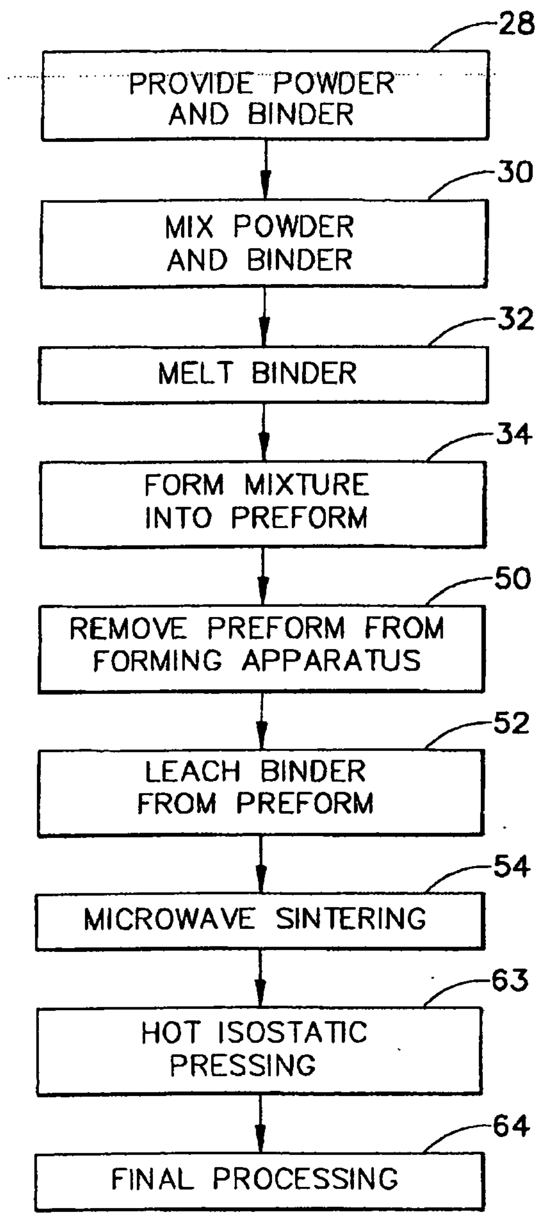
28
PROVIDE POWDER AND BINDER
30
MIX POWDER AND BINDER
32
MELT BINDER
34
FORM MIXTURE INTO PREFORM
50
REMOVE PREFORM FROM FORMING APPARATUS
52
LEACH BINDER FROM PREFORM
54
MICROWAVE SINTERING
63
HOT ISOSTATIC PRESSING
64
FINAL PROCESSING

FIG. 2

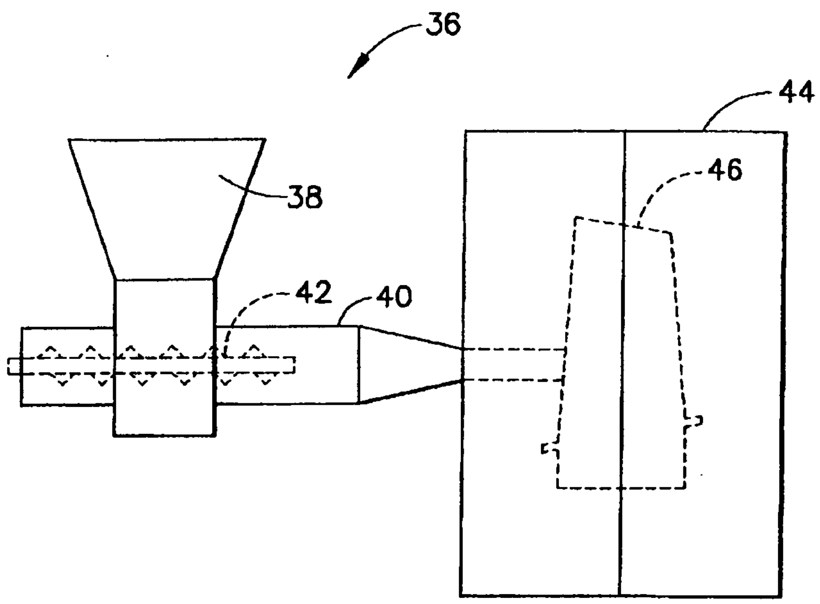

FIG. 3

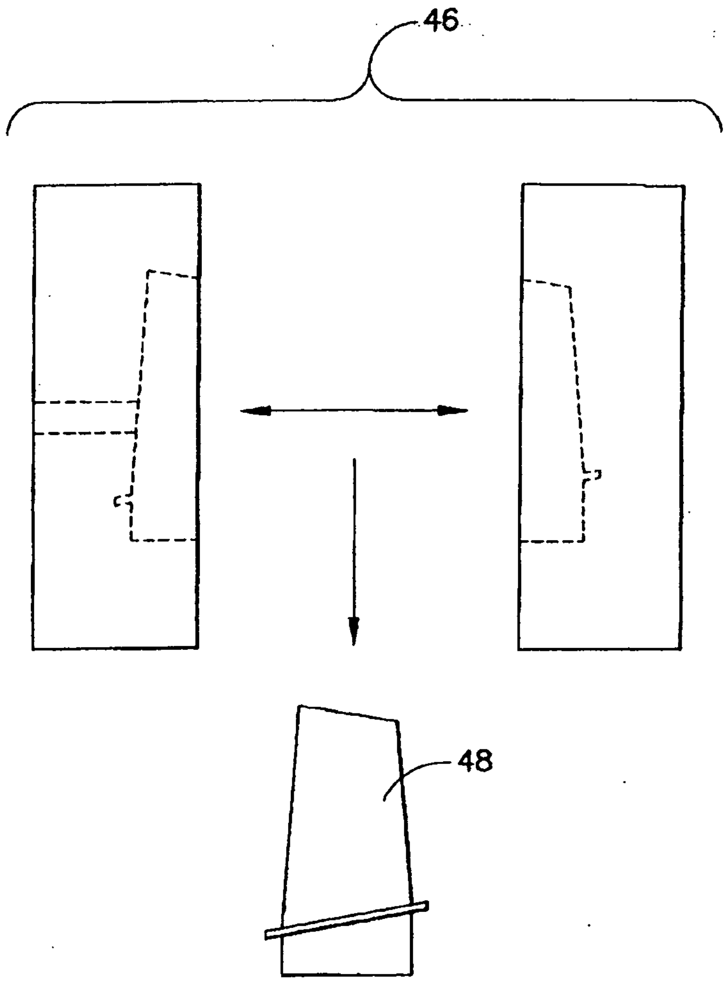

FIG. 4

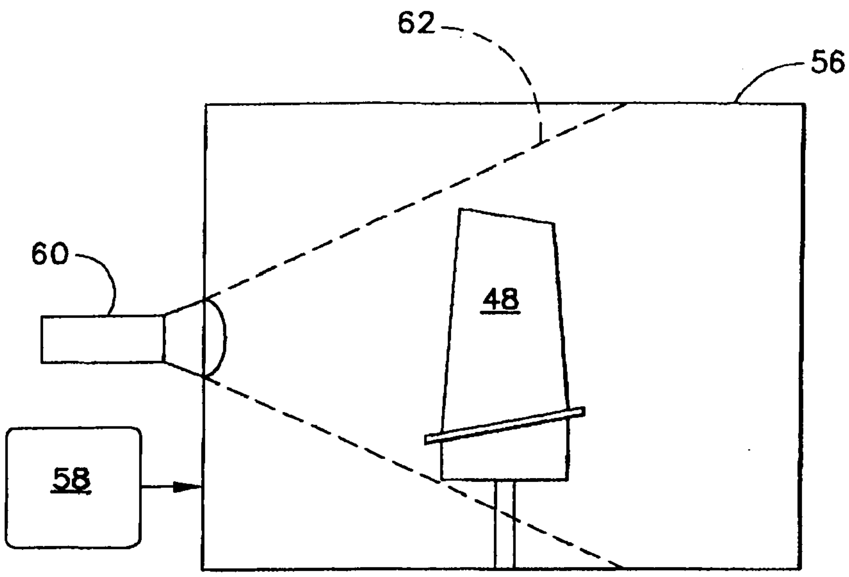

FIG. 5

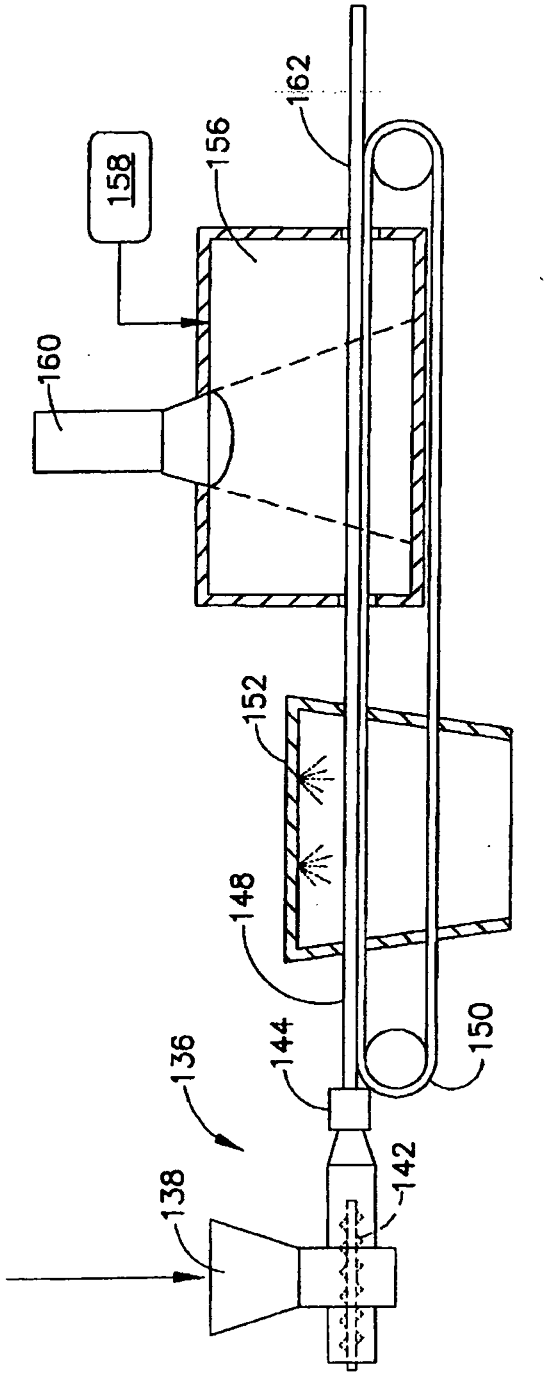

FIG. 6

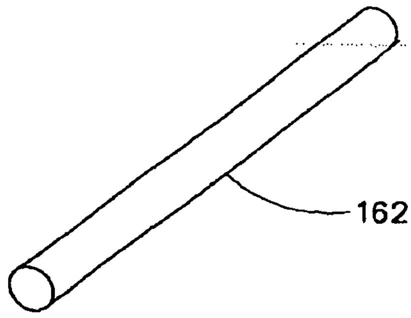

FIG. 7

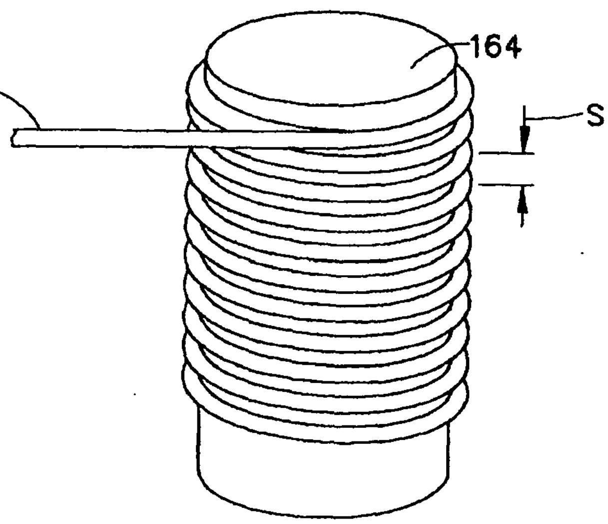

FIG. 8

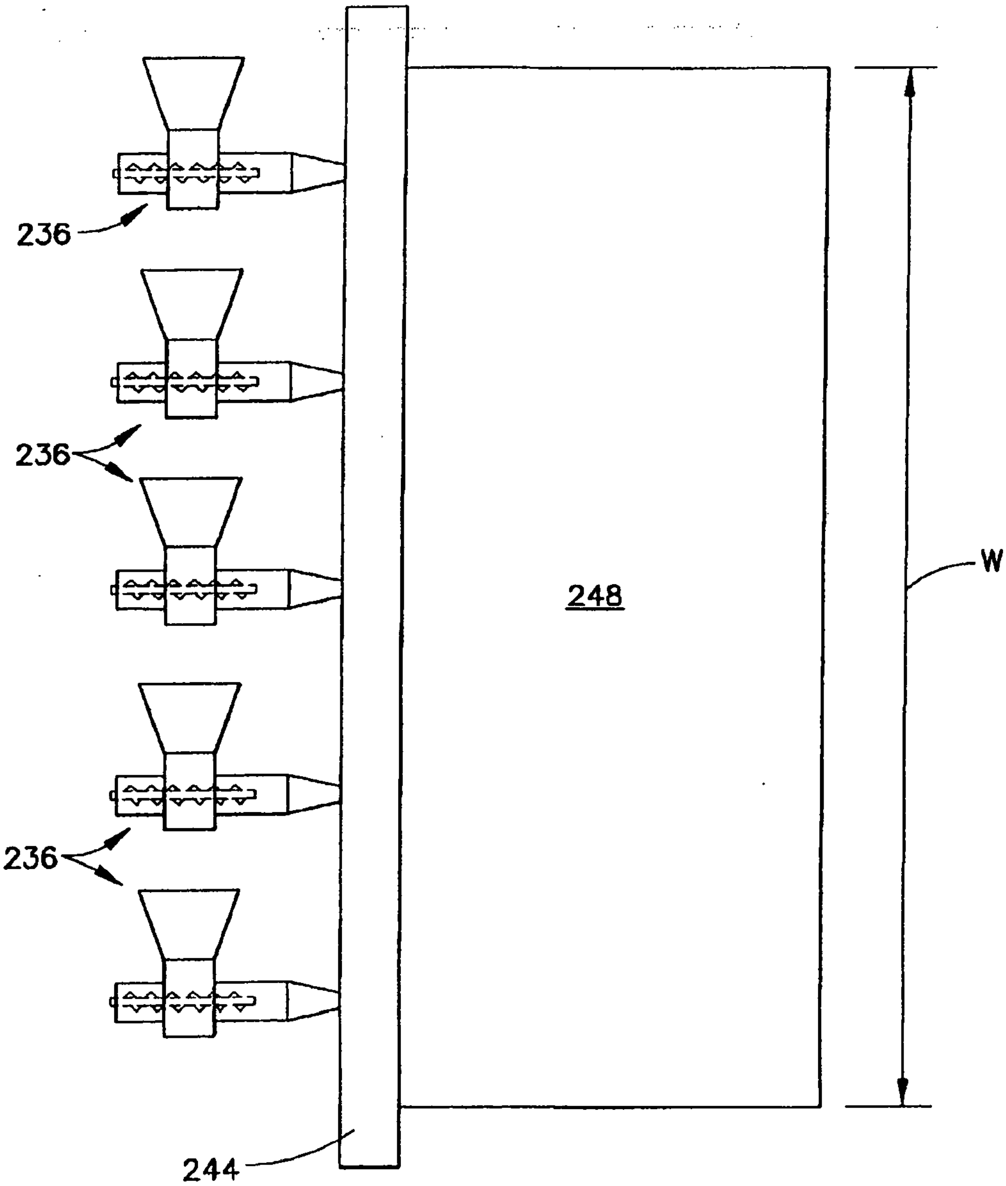

FIG. 9

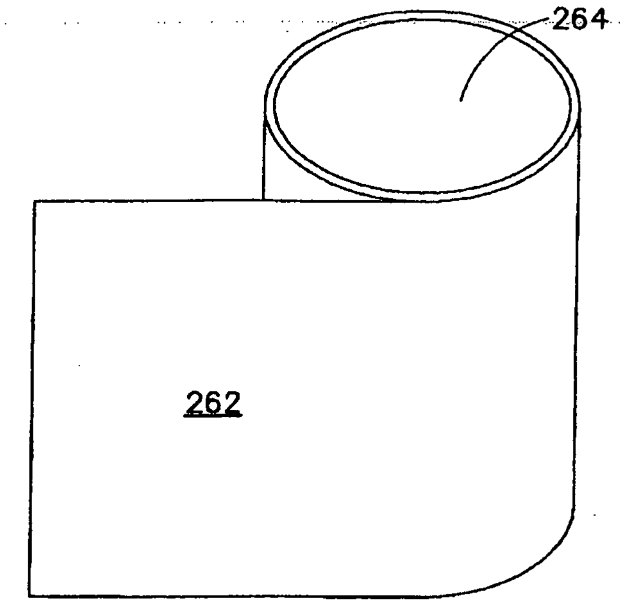

FIG. 10